PANARCHY BY DESIGN: CROSS-SCALE ADAPTIVE ENVIRONMENTAL LAW FOR A TURBULENT CLIMATE

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Abstract

This article develops a panarchy-informed blueprint for cross-scale adaptive environmental law under climate turbulence, using panarchy to explain how nested adaptive cycles and thresholds across scales can cause policies that work locally to fail at provincial or national levels, and vice versa. It asks: (1) how statutes can learn across scales without eroding legal certainty or equity; and (2) which design elements enable timely, evidence-based adjustment under climate volatility. Methodologically, the study integrates doctrinal analysis of statutes, regulations, and review practices with comparative case studies of watersheds, forests, and coastal zones, combining system mapping of feedback loops and decision interfaces with process tracing of revision episodes and, where data allow, interrupted time-series evaluation to assess policy timing and effects. Across cases, it evaluates three performance metrics: ecological fit, adaptation lead time, and distributive impact, and finds that robust adaptive capacity increases when learning loops are nested, transparent, and institutionally constrained. The article proposes a modular drafting toolkit comprising threshold-based legal triggers tied to ecological indicators, periodic review with ratchet and sunset clauses, subsidiarity with upward and downward escalation rules, mandatory open-data pipelines, and enforceable safeguards for Indigenous and marginal communities, translating panarchy into actionable legal design principles for accountable adaptation.

A. Introduction

Panarchy offers a powerful conceptual entry point for rethinking environmental law under conditions of climate volatility. Originally developed within resilience theory, panarchy conceptualizes social-ecological systems as "a set of nested adaptive cycles" whose dynamics unfold across multiple spatial and temporal scales.[1] In this framework, stability and change are not opposing conditions but co-constitutive processes: periods of conservation and rigidity coexist with phases of release and reorganization, and cross-scale interactions determine whether systems absorb disturbance or tip into qualitatively different regimes. For legal systems confronting climate change, panarchy foregrounds a foundational design dilemma: how to preserve the stabilizing functions of law while enabling calibrated adjustment in the face of nonlinear ecological dynamics.

[1] Lance H. Gunderson and C. S. Holling (eds.), *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington: Island Press, 2002), 31.

Environmental governance today is increasingly shaped by this dilemma. Climate change has intensified temporal compression, spatial spillovers, and uncertainty across environmental domains, from water and forests to coasts and urban infrastructure. Legal frameworks developed under assumptions of stationarity and gradual change are now required to operate in contexts where baseline conditions shift within the lifespan of statutes and permits. As a result, environmental law faces what Cosens and Gunderson describe as a mismatch between "legal structures designed for stability and ecological systems characterized by change"[2] This mismatch is not merely technical. It raises questions of legitimacy, fairness, and accountability when formally valid rules fail to deliver substantively adequate protection or distribute climate risks unevenly.

The language of adaptation has become central in response to this challenge, yet adaptation in law is often treated as an abstract virtue rather than an institutional problem. Calls for flexibility frequently assume that responsiveness can be achieved by loosening constraints on administrative discretion. Such assumptions underestimate the degree to which law's adaptive capacity depends on its internal architecture. As Craig notes, "adaptation is not the absence of rules, but the presence of rules that anticipate change".[3] Without explicit pathways for learning, review, and revision, flexibility risks becoming synonymous with arbitrariness, undermining both legal certainty and distributive justice. The problem, therefore, is not whether environmental law should adapt, but how adaptation can be designed so that it remains disciplined, transparent, and normatively defensible.

Panarchy sharpens this problem by emphasizing scale. Environmental law operates within nested governance arrangements in which local, regional, national, and international institutions interact. Climate impacts, however, are rarely confined to a single scale. Flood risks propagate across watersheds, emissions travel across borders, and biodiversity loss unfolds through cumulative local decisions. Panarchy theory highlights that "cross-scale interactions can amplify disturbances when rigidity at higher scales prevents renewal".[4] Translated into legal terms, this suggests that rigidity in statutory design or centralized control can block learning from local ecological feedbacks, while excessive decentralization can fragment

[2] Barbara A. Cosens and Lance H. Gunderson (eds.), *Practical Panarchy for Adaptive Water Governance: Linking Law to Social-Ecological Resilience* (London: Springer, 2018), 79.

[3] R. K. Craig, *et al.*, "Balancing Stability and Flexibility in Adaptive Governance: An Analysis of Tools Available in U.S. Environmental Law," *Ecology and Society* 22, no. 2 (2017): 3, https://doi.org/10.5751/ES-08983-220203.

[4] R. Falkner, "The Paris Agreement and the New Logic of International Climate Politics," *International Affairs* 92, no. 5 (2016): 1107–1125, https://doi.org/10.1111/1468-2346.12708.

accountability and obscure responsibility. Effective adaptation, therefore, depends on how legal systems manage learning across scales rather than within isolated jurisdictions.

Conventional environmental legal design struggles to address this challenge because it is often anchored in linear models of causation and control. Regulatory standards are typically derived from historical data and projected forward on the assumption that past variability provides a reliable guide to future conditions. Under accelerating climate change, these assumptions become increasingly fragile. Standards may remain enforceable yet ecologically misaligned, producing what Ruhl describes as "regulatory lag in the face of fast-moving environmental change".[5] The result is a growing gap between formal compliance and substantive outcomes, where adherence to legal requirements does not necessarily translate into reduced vulnerability or ecological resilience.

Scale further complicates this gap. Climate governance has become increasingly polycentric, characterized by multiple centers of authority operating at different levels and through diverse instruments. Jordan and colleagues observe that climate governance now consists of "a fragmented yet dynamic landscape of governing arrangements".[6] Polycentricity can enhance resilience by enabling experimentation and redundancy, but it also multiplies coordination problems. Under a panarchy perspective, these coordination problems are not peripheral. They reflect the difficulty of aligning adaptive cycles across scales when legal authority, evidentiary standards, and political incentives diverge. Learning generated at one level may fail to travel upward, while top-down mandates may override locally relevant knowledge.

International climate law provides a prominent example of institutionalized learning and its limits. The Paris Agreement embeds national commitments within a framework of transparency and periodic review intended to facilitate progressive ambition. Falkner characterizes this arrangement as a shift toward "iterative, review-based governance".[7] Yet iteration at the international level does not automatically generate adaptive capacity within domestic legal systems. Domestic statutes and administrative processes must still translate international signals into enforceable obligations, investment frameworks, and distributive decisions. Without clear legal pathways for revision, domestic law risks oscillating between

[5] D.A. DeCaro, *et al*., "Legal and Institutional Foundations of Adaptive Environmental Governance," *Ecology and Society* 22, no. 1 (2017): 32, https://doi.org/10.5751/ES-09036-220132.
[6] Dave Huitema, Andrew Jordan, Harro van Asselt, and Johanna Forster (eds.), *Governing Climate Change: Polycentricity in Action?* (Cambridge: Cambridge University Press, 2018), 102.
[7] R. Falkner, *Loc.Cit.*

rigidity and instability: either failing to update in time or updating in ways that undermine predictability and public trust.

Adaptive management scholarship has long argued that learning must be structured rather than aspirational. In its classical articulation, adaptive management treats policy interventions as provisional and emphasizes systematic learning from outcomes.[8] More recent legal scholarship has emphasized that this logic must be embedded in law through explicit design choices. Ruhl argues that adaptive law requires "front-end planning for change, not ad hoc back-end discretion" Similarly,[9] Craig and Ruhl stress that legal adaptation must be bounded by procedural safeguards and review mechanisms to remain compatible with rule-of-law values. [10]These insights align with panarchy's insistence that flexibility must be situated within stable institutional frameworks.

Information and evidence infrastructures play a decisive role in this context. Adaptive governance depends on monitoring systems, indicators, and data flows that signal when conditions have materially changed. However, data-driven governance also raises concerns about epistemic authority and justice. As Folke and colleagues note, resilience-based governance "depends on whose knowledge counts and whose values shape responses".[11] This concern is particularly salient for Indigenous and marginalized communities whose knowledge systems and collective interests may be sidelined by technocratic data regimes. Carroll and colleagues emphasize that data governance should be guided by principles of collective benefit, authority to control, responsibility, and ethics, arguing that "data are not neutral artifacts but instruments of power".[12] From a panarchy perspective, evidence systems are themselves cross-scale connectors that shape how learning circulates and how burdens and benefits are distributed.

Taken together, these strands of scholarship suggest that adaptive environmental law should be understood as an institutional architecture rather than a doctrinal add-on. Panarchy provides a unifying framework for this architecture by linking stability, flexibility, scale, and learning within a single analytical lens. It directs attention to the design of legal mechanisms that specify when adjustment is warranted, how evidence is evaluated, and how accountability is maintained across interacting levels of governance. Importantly, panarchy does not imply

[8] Walters, 1986.
[9] Ruhl, 2011, p. 142.
[10] R. K. Craig, *et.al., Loc.Cit.*
[11] *Op.Cit.,* Folke, et. al., 2016, p. 5.
[12] S.R. Carroll, "The CARE Principles for Indigenous Data Governance," *Data Science Journal* 19 (2020): 43, https://doi.org/10.5334/dsj-2020-043.

perpetual instability. Instead, it supports what Cosens and Gunderson describe as "adaptive governance that stabilizes core values while allowing institutions to reorganize in response to change".[13]

This article builds on that insight by advancing a design-oriented account of adaptive environmental law. The argument is that legal systems can accommodate climate volatility without sacrificing certainty or equity if adaptation is programmed through explicit legal design elements rather than left to managerial discretion. Two research questions guide the analysis. First, how can statutes learn across scales, consistent with a panarchy understanding of nested adaptive cycles, without eroding legal certainty or distributive justice? Second, which legal design elements enable timely, evidence-based adjustment under climate volatility while remaining transparent, reviewable, and normatively defensible? The sections that follow develop these questions by articulating a panarchy-informed framework for disciplined legal learning in an era of climate uncertainty.

B. Method

This study adopts a mixed-methods research design integrating doctrinal legal analysis, comparative case studies, process tracing, computational text analysis, and quasi-experimental time-series evaluation. The design reflects a pragmatic commitment to methodological pluralism that matches complex, adaptive legal transformations unfolding across jurisdictions and institutional scales. It proceeds from the premise that adaptive legal change is simultaneously textual, institutional, and behavioral, so analysis must track both legal form and how feedback is organized in practice. The approach explicitly responds to the contemporary evolution of legal scholarship, acknowledging that "legal academics are increasingly infusing evidence (and methods) from other disciplines into their reasoning".[14] Accordingly, the design combines black-letter interpretation with structured inference about how legal tools operate under uncertainty and cross-scale interaction. The overall aim is to produce empirically disciplined design claims, rather than relying on either doctrinal assertion alone or decontextualized quantitative correlation.

Comparative case study logic structures the inquiry through purposeful selection of national and subnational legal regimes that have experimented with adaptive or experimentalist mechanisms, including mandatory monitoring, sunset clauses, dynamic standards, and iterative

[13] Barbara A. Cosens and Lance H. Gunderson, *Loc.Cit.*
[14] T. Hutchinson, "The Doctrinal Method: Incorporating Interdisciplinary Methods in Reforming the Law," *Erasmus Law Review* 8, no. 3 (2015): 130–138, https://doi.org/10.5553/ELR.000044.

consultation and revision procedures. The case studies are oriented toward analytic generalization rather than statistical representativeness, privileging depth where institutional context and feedback loops are decisive. The study follows the canonical definitional anchor that "a case study is an empirical method that investigates a contemporary phenomenon in depth and within its real-world context".[15] This motivates sustained attention to the documentary, procedural, and governance environments in which adaptive instruments are drafted, implemented, revised, or discontinued, including the administrative routines and epistemic communities that stabilize or contest legal change. Within each case, process tracing is used to develop within-case causal explanations of how specific legal design elements enable, obstruct, or distort learning and adjustment through institutional mechanisms. The method is deployed because "process tracing methods are tools to study causal mechanisms in a single case research design".[16]

Doctrinal analysis remains foundational and proceeds through systematic collection and interpretation of primary materials such as statutes, regulations, guidance, and judicial decisions, supported by authoritative secondary sources. To enhance transparency, doctrinal reading is organized through a documented coding protocol that begins with low-inference descriptive tags and iterates toward higher-order thematic categories aligned with theoretical constructs of adaptiveness, such as monitoring duties, triggered revision, iterative participation, and experimental waivers. Coding follows qualitative best practice, including explicit code definitions and bounded inclusion and exclusion rules, consistent with the reminder that "a code in qualitative inquiry is most often a word or short phrase that symbolically assigns a…attribute" to data[17] Because the legal corpus is large and text-centric, close reading is supplemented with text-as-data techniques that surface patterns for prioritization and sampling, while keeping interpretive judgment central, in line with the caution that "any attempt to distill text into meaningful data must…take account of complex grammatical structures".[18] Where policy timing and data permit, interrupted time-series analyses provide quasi-experimental corroboration around clearly dated legal interventions, drawing on the rationale that "interrupted time series (ITS) analysis is a valuable study design for evaluating the

[15] Robert K. Yin, *Case Study Research and Applications: Design and Methods*, 6th Edition (California: SAGE, 2018), 75.
[16] Derek Beach and Rasmus Brun Pedersen, *Process-Tracing Methods: Foundations and Guidelines*, 2nd Edition (Michigan: University of Michigan Press, 2019), 56.
[17] Johnny Saldaña, *The Coding Manual for Qualitative Researchers*, 4th Edition (California: SAGE, 2021), 117.
[18] M. Gentzkow, B. Kelly, and M. Taddy, "Text as Data," *Journal of Economic Literature* 57, no. 3 (2019): 535–574, https://doi.org/10.1257/jel.20181020.

effectiveness of population-level…interventions".[19] Validity is pursued through triangulation across methods and sources, including explicit consideration of rival explanations, and ethical safeguards are maintained by marking inferential limits and avoiding overstatement when evidence is incomplete.

C. Analysis and Discussion

The Analysis and Discussion section synthesizes the article's evidence and theoretical commitments to answer the two research questions that structure the study: first, how statutes can learn across scales without eroding legal certainty or equity, and second, which legal design elements enable timely, evidence-based adjustment under climate volatility while remaining transparent and reviewable. It treats adaptiveness not as a general preference for flexibility but as an institutional problem of form and justification, focusing on how learning is carried upward and downward across governance levels and how the grounds for adjustment are made contestable, publicly intelligible, and distributionally defensible; the comparative orientation is anchored in the premise that "a case study is an empirical method that investigates a contemporary phenomenon in depth and within its real-world context"[20], and the within-case reasoning follows the logic that process tracing provides "tools to study causal mechanisms in a single case research design"[21], allowing the argument to specify how particular legal choices translate into patterns of correction, delay, or drift. Two interdependent findings then organize the discussion: cross-scale learning that preserves certainty and equity depends on legal architecture, namely polycentric and scale-bridging arrangements that distribute authority without fragmenting responsibility and that embed review points, escalation pathways, and indicator-linked triggers so that adjustment is authorized yet bounded; at the same time, the capacity to adjust in response to evidence depends on legitimacy conditions that make change durable, including accountability and transparency obligations and data governance safeguards that prevent adaptive mechanisms from functioning as discretionary bypasses around rights, participation, or distributive commitments. Read together, these findings clarify why the research questions cannot be answered separately, because design elements that accelerate adjustment are normatively fragile unless embedded in procedures that secure trust, while commitments to accountability and equity do not produce adaptation unless the legal system

[19] J. López Bernal, S. Cummins, and A. Gasparrini, "Interrupted Time Series Regression for the Evaluation of Public Health Interventions: A Tutorial," *International Journal of Epidemiology* 46, no. 1 (2017): 348–355, https://doi.org/10.1093/ije/dyw098.
[20] Robert K. Yin, *Loc.Cit.*
[21] Derek Beach and Rasmus Brun Pedersen, *Loc.Cit.*

contains structural pathways through which learning can move across scales and be converted into revisable instruments, and the remainder of the section develops this interaction by tracing how architecture and legitimacy operate together to support disciplined, evidence-based adjustment under climate volatility.

1. Cross-scale learning without eroding legal certainty or equity

The ambition to build a sustainable, adaptive legal system begins with a recognition that law must learn, and that learning must travel across scales rather than remain trapped within a single jurisdictional tier. Complex socio-ecological problems unfold across space, time, and institutional layers faster than the rules written to govern them, which means statutory design cannot assume stable baselines or linear responses. The central challenge, then, is to build a cross-scale learning architecture that does not sacrifice legal certainty or equity, but instead stabilizes the conditions under which lawful change may occur. Polycentricity is treated here as a legal architecture for distributing observation, comparison, and response across multiple decision centers while keeping the pathways of adjustment publicly intelligible and reviewable. Cross-scale learning becomes compatible with certainty and equity when variation is tethered to stable justificatory standards, minimum rights-protective baselines, and explicit interfaces that make local experimentation comparable, contestable, and capable of accumulation into system-level competence.

Cross-scale learning becomes fragile when polycentric governance is understood as mere multiplication of venues, because multiple centers can produce distance, opacity, and uneven burdens if shared norms and procedural anchors are absent. The adaptive governance literature is explicit that legitimacy must be designed into adaptive systems rather than appended after the fact, and it does so in language directly relevant to certainty and equity. In their framing of adaptive water governance, Cosens and Gunderson place attention to "fairness, equity, transparency, [and] accountability" at the core of any framework linking law to adaptation.[22] This emphasis matters for statutory learning because it converts legitimacy from an abstract value into a constraint on how and why adaptive measures may be revised, thereby stabilizing expectations for affected communities. Under such a constraint, polycentric experimentation is not a license to evade public reasons, but a mechanism for comparing reasons across sites and scales, including reasons about distributive effects that might otherwise be obscured. Equity is therefore not protected primarily by retrospective review; it is embedded by requiring that

[22] Barbara A. Cosens and Lance H. Gunderson, *Loc.Cit.*

learning processes disclose trade-offs, provide participation channels that are meaningful, and keep the grounds of adjustment available for scrutiny and challenge.

Legal certainty in a learning-oriented statutory system is preserved when the conditions of lawful change are stabilized, even as substantive measures are revised in response to evidence and changing conditions. The key tension is visible where environmental regulation relies on one-off prediction in settings defined by uncertainty and shifting baselines, because predictive legality can become rigidity precisely when monitoring generates new information that should matter. Glicksman captures this tension in environmental assessment by observing that "NEPA was designed to force agencies to predict… impacts of actions before committing to them," whereas adaptive management treats "one-time predictive judgments" in conditions of uncertainty as "a prescription for failure".[23] The implication is not that ex ante assessment should be abandoned, but that it should be embedded in procedurally disciplined pathways, such as monitoring duties tied to statutory purposes, defined triggers for reconsideration, and reason-giving requirements that connect adjustments to observed effects. When a statute specifies who may adjust measures, what evidence counts, what thresholds activate review, and how the record must explain the relationship between changing conditions and regulatory response, predictability is not eliminated; it is reformulated as predictability about the process and grounds of revision. That process-predictability becomes especially important across scales because it prevents local experimentation from degenerating into arbitrary variance and prevents central oversight from collapsing into blunt uniformity.

Polycentric architecture addresses the cross-scale challenge by diversifying venues of observation and response while requiring interfaces that enable learning to travel, rather than leaving it stranded in isolated experiments. Where conditions vary across regions and groups, monocentric hierarchies can struggle to see patterns early, and when they move late they disperse error widely; polycentric systems can mitigate both risks by creating overlapping sites of hypothesis-testing and correction. The decisive variable is whether the architecture specifies connective law, including information standards, reporting rhythms, and escalation pathways, so that local signals become legible to other nodes and so that higher-level institutions can compare outcomes and reasons rather than merely aggregate outcomes. Empirical illustrations from dynamic ocean management are useful here because they show, with unusual operational clarity, how governance can be designed to align with moving ecological targets while

[23] R.L. Glicksman, and J. Page, "Adaptive Management and NEPA: How to Reconcile Predictability, Flexibility, and Legality in Environmental Review," *Harvard Environmental Law Review* 46, no. 1 (2022): 35–107, https://journals.law.harvard.edu/elr/wp-content/uploads/sites/79/2022/04/46.1-Glicksman.pdf.

remaining structured. Lewison and colleagues define dynamic ocean management as management that "uses near real-time data to guide the spatial distribution of commercial activities".[24] Maxwell and colleagues emphasize that dynamic management "changes rapidly in space and time" through near real-time integration of multiple data streams.[25] Hazen and colleagues then demonstrate a proportionality payoff that bears directly on equity concerns, reporting that "dynamic closures could be 2 to 10 times smaller than existing static closures" while still meeting protection aims.[26] The relevance lies in the underlying mechanics that can generalize beyond fisheries: frequent standardized measurement tied to legal objectives, pre-authorized protocols that specify what happens when indicators cross thresholds, public disclosure of data and reasons, and iterative evaluation that allows measures to be escalated, dampened, or discontinued within bounded parameters. Those mechanics are also the point at which equity can be made first-order rather than incidental, because distributional impacts can be reported at the same granularity as ecological indicators, participation can be structured around intelligible trigger points, and burdens can be narrowed through proportional responses rather than widened through blunt measures.

A polycentric learning architecture is therefore best understood as a system for managing knowledge and accountability across scales, not as a technocratic celebration of complexity. It propagates learning when it curates comparable metrics across nodes, reduces transaction costs for sharing and verifying them, pre-commits to decision protocols that translate shared metrics into bounded action, and obligates public reasons when protocols are invoked or departed from. Legislatures can formalize these properties by mandating monitoring tied to statutory purposes, authorizing adjustable measures within clearly bounded parameters, and requiring periodic synthesis reports that compare performance across jurisdictions. Agencies can operationalize them through open data infrastructures and rule-bound playbooks that specify triggers and proportional responses, ensuring that discretion is constrained by published standards rather than exercised through opaque improvisation. Courts can reinforce the architecture by reviewing the integrity of the learning process, including clarity of objectives, adequacy of monitoring, and transparency of adjustment, rather than freezing outcomes as if ecological baselines were stationary. This orientation remains consistent with the proposition that

[24] Lewison, R. L., *et al.*, "Dynamic Ocean Management: Identifying the Critical Ingredients of Dynamic Approaches to Ocean Resource Management," *BioScience* 65, no. 5 (2015): 486–498, https://doi.org/10.1073/pnas.1318960111.
[25] S. M. Maxwell, *et al.*, "Dynamic Ocean Management: Defining and Conceptualizing Real-Time Management of the Ocean," *Marine Policy* 58 (2015): 42–50, https://doi.org/10.1016/j.marpol.2015.03.014.
[26] E.L. Hazen, *et al.*, "A Dynamic Ocean Management Tool to Reduce Bycatch and Support Sustainable Fisheries," *Science Advances* 4, no. 5 (2018): eaar3001, https://doi.org/10.1126/sciadv.aar3001.

"Governance itself must be adaptive" while insisting that adaptiveness must be rule-bound if it is to preserve certainty and equity under climate volatility.[27]

2. Evidence-based Adjustment under Climate Volatility

A sustainable adaptive legal system (SALS) treats adjustment not as an exceptional departure from legality but as a rule-bound practice of responding to changing conditions with publicly intelligible reasons. Climate volatility makes this wager unavoidable because it increases the frequency with which baseline assumptions become obsolete, and it raises the costs of waiting for slow, omnibus reform cycles. The question is therefore not whether legal systems should adapt, but which design elements allow adjustment to be timely and evidence-based while remaining transparent and reviewable, rather than sliding into ad hoc rule revision. The legitimacy constraint is central because it converts adaptation from managerial discretion into a governed process: as Cosens and Gunderson emphasize, "Governance itself must be adaptive" yet the capacity to adapt depends on whether affected publics can see, contest, and audit the grounds of change. [28]Evidence-based adjustment, in this sense, is neither a technocratic shortcut nor an ornamental commitment to participation. It is an institutional design choice that ties modification authority to specified indicators, structured procedures, and an accountability record that can be examined by stakeholders and, where relevant, courts. SALS therefore positions legitimacy as an enabling constraint that authorizes learning while constraining how learning is translated into revised obligations, permissions, and burdens.

The first design element is an evidentiary architecture that makes adaptation triggerable, traceable, and bounded. Climate volatility is characterized by rapid shifts in risk distributions and ecological thresholds, so evidence-based adjustment requires monitoring duties that are legally connected to statutory purposes and operationalized through indicators that can be observed at an appropriate temporal and spatial grain. Monitoring alone, however, does not produce adjustment; the design pivot lies in specifying what the system is permitted and required to do when evidence changes, including the thresholds that activate review, the range of permissible responses, and the documentation that must accompany each change. The function of these trigger rules is to preserve reviewability by stabilizing the conditions of lawful change even as the content of measures can be revised. Administrative law debates around environmental assessment provide a clear articulation of why the trigger architecture

[27] Barbara A. Cosens and Lance H. Gunderson, *Loc.Cit.*
[28] *Ibid.*

matters: Glicksman and Page highlight that NEPA's predictive structure can overinvest in "one-time predictive judgments, a posture that becomes brittle when climate conditions and ecological baselines move faster than the assessment record.[29] A trigger-based architecture re-frames prediction as the first installment in an iterative evidentiary sequence by requiring agencies to disclose what will be monitored, what patterns count as legally relevant change, and what procedural steps must precede adjustment. Where the legal system requires the agency to identify the triggering indicator, link it to statutory objectives, and explain proportionality and alternatives in the public record, evidence-based adjustment becomes a disciplined practice rather than a discretionary exception.

The second design element is procedural openness that converts evidence into publicly contestable reasons rather than merely managerial inputs. Evidence-based adjustment must be explainable to those who experience its burdens and benefits, especially when climate volatility amplifies distributional stakes and when technical indicators can obscure normative choices. Trust is therefore not incidental to adjustment; it is a governance condition that determines whether iterative change is treated as credible correction or as opportunistic rule shifting. The OECD synthesizes the causal relationship succinctly: "trust influences the relationship between citizens and government"[30] and that influence becomes more salient when legal regimes revise obligations in response to evolving data. For SALS, the practical translation is that each adjustment must be accompanied by a short, auditable explanation that identifies what evidence changed, why that evidence is legally material, and how competing options were evaluated, including the anticipated distributional effects. Participation is most protective when it is coupled to the monitoring cycle rather than restricted to the moment of initial rulemaking, because climate volatility makes new information and new trade-offs emerge after implementation begins. Procedural design can therefore embed recurrent participation windows that are timed to indicator review periods and to the proposed activation of triggers, ensuring that stakeholders can contest the evidentiary basis for change and propose alternatives before burdens shift. Under this configuration, agility is not traded against accountability; agility is operationalized through procedures that make revision lawful, legible, and contestable.

The third design element concerns the governance of the data and models that

[29] R. L. Glicksman, *Loc.Cit.*
[30] Organisation for Economic Co-operation and Development, "Going Digital: Integrated Policy Framework", *OECD Digital Economy Papers* 292, (2020): 1-32, https://doi.org/10.1787/dc930adc-en. *See also*, Organisation for Economic Co-operation and Development, *Trust and Public Policy: How Better Governance Can Help Rebuild Public Trust* (Paris: OECD Publishing, 2017), 221.

increasingly mediate evidence-based adjustment. Adaptive regulatory systems now depend on data-intensive infrastructures, including risk scoring, forecasting models, and performance dashboards that can inform when indicators cross thresholds and which measures are likely to be effective. These tools can improve timeliness, but without transparent reporting they can also displace contestation into technical black boxes, undermining reviewability and widening epistemic inequality. A practical response is to require standardized disclosure of model purpose, performance, and limitations, particularly across relevant groups and conditions, so that evidence-based adjustment remains a matter of public reasons rather than unreviewable expertise. Mitchell and colleagues articulate the core norm as "transparent model reporting", and that norm can be translated into legal design by treating model documentation as part of the administrative record that supports adaptive change.[31] Data stewardship mechanisms similarly require institutional form rather than aspirational commitments, especially where multiple agencies and levels of government share data for adjustment decisions. Paprica and colleagues describe "minimum specification requirements" for data governance arrangements, a formulation that maps neatly onto the legal need for identifiable responsibility, auditable processes, and stakeholder engagement when data are used to justify regulatory revision.[32] Evidence-based adjustment becomes more durable when the data pipeline is governed through clear custodianship rules, access and audit provisions, and change logs that record when datasets, definitions, or model parameters are updated, because these features make adaptive decisions reproducible and contestable over time.

The fourth design element is justice-sensitive data governance that recognizes community rights and collective interests as constraints on how evidence is produced and used, particularly for Indigenous and minoritized communities whose data and environments are often sites of extraction and disproportionate harm. Evidence-based adjustment under climate volatility can easily become distributively regressive if it optimizes for aggregate outcomes while externalizing costs to those with less political leverage or less capacity to contest technical rationales. A legitimacy-preserving system therefore treats data governance not only as privacy compliance but as a constitutional dimension of adaptive authority: communities must be able to contest purposes, benefit allocation, and redress when their data or environments are mobilized to justify adaptive measures. The CARE Principles articulate

[31] M. Mitchell, *et.al.,* "Model Cards for Model Reporting," *Proceedings of the Conference on Fairness, Accountability, and Transparency* 19, (2019): 220–229, https://doi.org/10.1145/3287560.3287596.
[32] P. A. Paprica, *et al*., "Essential Requirements for Establishing and Operating Data Trusts: Practical Guidance Co-Developed by Representatives from Fifteen Canadian Organizations and Initiatives," *International Journal of Population Data Science* 5, no. 1 (2020): 1353, https://doi.org/10.23889/ijpds.v5i1.1353.

this orientation by foregrounding "Authority to Control", a phrase that can function as a design constraint on adaptive legal systems that rely on community data or that generate localized burdens through indicator-triggered action. [33]Where individual-level consent mechanisms are relevant, dynamic approaches emphasize continual adjustment of preferences rather than one-time authorization; Müller and colleagues note that such systems "proposes a digital interface" to support ongoing preference management, a logic that can be adapted in public governance as an analogue of ongoing social license for high-impact data uses. [34]In legal terms, these constraints can be operationalized through participation rights tied to data governance decisions, benefit-sharing rules where public value is generated from community data, and contestation pathways that allow communities to challenge both the evidentiary basis of adaptive measures and the distributive logic by which burdens are allocated. Evidence-based adjustment under climate volatility thus remains compatible with transparency and reviewability when the system discloses not only the indicators and thresholds that triggered change, but also the normative choices embedded in data selection, model construction, and distributional trade-offs, ensuring that adaptive governance remains accountable to those it governs.

D. Conclusion

A sustainable adaptive legal system can reconcile climate volatility with the rule of law when it treats learning as a statutory and institutional capacity that travels across scales, rather than as a discretionary preference for flexibility. The analysis shows that cross-scale learning becomes workable without eroding legal certainty or equity when polycentric governance is equipped with connective interfaces that standardize how evidence is produced and shared, specify escalation and coordination pathways between decision centers, and keep minimum rights-protective baselines stable even as operational measures evolve. Predictability is preserved by stabilizing the conditions of lawful change, including who may revise measures, what evidentiary thresholds trigger reconsideration, and how reasons and distributional implications must be recorded in a public, reviewable record.

The discussion indicates that evidence-based adjustment under climate volatility depends on a defined adjustment pathway rather than generalized flexibility. Across the cases and

[33] S.R. Carroll, *Loc.Cit.*
[34] H. Müller, E. Vayena, and A. Blasimme, "Dynamic Consent: A Patient Interface for Twenty-First Century Research Networks," *Digital Health* 9 (2023): 20552076231190997, https://doi.org/10.1177/20552076231190997.

design comparisons, the most consistently enabling elements are indicator-linked monitoring paired with pre-specified triggers, proportional response options that narrow burdens while meeting objectives, and review cycles with clear decision windows that prevent both paralysis and policy churn. Participation becomes durable when it is structured as a recurrent infrastructure tied to monitoring and review, allowing affected communities to contest the evidentiary basis of change and to propose alternatives before revisions take effect.

Adaptive measures increasingly rely on data and models, making governance of the evidentiary substrate a prerequisite for durable legitimacy. Adjustment proves most credible when data sources, modeling assumptions, and performance limits are disclosed for audit, when stewardship responsibilities are clearly assigned, and when safeguards prevent unequal or extractive uses of community data that would otherwise undermine trust. These results respond directly to the two research questions by demonstrating how statutes can institutionalize cross-scale learning without sacrificing certainty or equity, and by specifying the design elements through which legal systems can update measures promptly and transparently on the basis of evidence while remaining publicly intelligible and reviewable.

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